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Sampling Procedures for Ground Water Quality Investigations

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SAMPLING PROCEDURES FOR GROUND WATER QUALITY INVESTIGATIONS

by

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16. ABSTRACT

To provide a realistic assessment of current and potential pollution problems and a rational basis for ground water quality protection, it is necessary to collect representative samples from this remote and relatively inaccessible environment. This article presents some procedures currently utilized to sample ground water and subsurface earth materials for microbial and inorganic and organic chemical parameters.

In selecting a sampling procedure, a number of considerations are described based on the objectives of the sampling program, characteristics of pollutants, nature of pollution source, and hydrogeology of the area. Various techniques for constructing sampling wells and for withdrawing samples are also noted. For situations where samples of subsurface earth materials are required to adequately assess ground-water quality threats, procedures are described for collecting, handling, and processing core samples.

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INTRODUCTION

Prior to the last decade, conventional wisdom presumed that ground water resources were protected from pollution by a soil mantle which filtered, adsorbed, degraded or otherwise prevented contaminants from reaching the ground water. This optimism has been replaced in recent years by concern over the numerous instances of contaminants being discovered in water supplies hundreds of feet below the ground surface.

In the United States, recent environmental legislation has recognized the importance of ground water quality protection and the stresses that man's activities, especially waste disposal, place on this vital national resource. In order to assess the impact of such activities on ground water quality and, hence, to provide a rational basis for its protection, the behavior of pollutants in the subsurface and the processes governing this behavior must be evaluated.

Because the subsurface is a relatively remote and inaccessible environment, sampling is often difficult even for the most routine water quality parameters. Collection of subsurface samples for the identification of specific organic compounds is a relatively new and even more tedious and complex process that differs substantially from routine methods used for inorganic compounds. Analyses for organic compounds are both expensive and time-consuming. Yet the

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thousands of dollars spent for the evaluation of a sample for a suite of organic compounds are completely wasted if the samples are not properly collected and stored before analysis.

OBJECTIVES OF SAMPLING

There are several reasons for sampling ground water. If the objective is limited to determining the presence or absence of a conservative pollutant in a particular water supply, it is simple and relatively inexpensive to collect a sample at a water tap. However, if the objective is to characterize a contamination event by defining the horizontal and vertical distribution of an organic pollutant or pollutants and predicting the eventual fate, then monitoring wells, soil cores and special sampling equipment may increase efforts and costs several orders of magnitude. In the former case, the purpose of the sample collection activity is known and limited in scope. In the latter case, there is need to be concerned not with the point data itself, but as a component of a network wherein data is developed suitable for constructing an image of the piezometric surface and the contaminant plume (1)(2).

A monitoring well samples a very small part of an aquifer horizontally and in many cases, vertically. Unlike surface water where a sample can be arbitrarily taken at any point in the system, moving a ground water sampling point implies the installation of additional monitoring wells (3). Because of the difficulty and expense, it is essential that sampling objectives be firmly established well in advance of field activities. These objectives will dictate the parameters to be measured, the necessary reliability of the water quality data and analytical methodology and thence the sampling procedures necessary to meet these objectives.

PRELIMINARY EVALUATIONS

In addition to the objectives of the sampling program, there are three other principal considerations that determine the sampling procedures selected--characteristic of the pollutants, nature of the possible pollutant source, and hydrogeology of the area of interest (4).

Characteristics of the Pollutant

The unstable nature of many chemical, physical, and microbial constituents in the subsurface limits the options for sample collection and analysis. The subsurface is a unique heterogenous environment and maintaining the integrity of a sample from its natural environment to the time of analysis is often a very difficult process. Because the physical, chemical, and microbial aspects of the environment are so closely interrelated, it is very difficult to change one without affecting the others. However, in selecting ground water sampling procedures, there are definite aspects of each that must be considered to maintain sample integrity.

Ground waters are usually well insulated, therefore temperature fluctuations are minimal in their natural environment; however, once removed to the surface, temperature may change very rapidly and influence many aspects of the water quality.

Many ions normally present in only trace amounts in ground waters may not remain unchanged when sampled because of chemical and physical reactions such as oxidation, precipitation, adsorption and ion exchange.

Organic compounds in the parts per billion range may be significant to human health in contrast to the more innocuous inorganic compounds. Such considerations combined with the great complexity of these compounds accentuate the sampling problems associated with adsorption, contamination and volatility.

Materials from which pumps, samplers, discharge lines, storage containers and well casings are constructed must receive careful consideration. Metals may strongly adsorb organic compounds and there is the possibility of reactions catalyzed by metal surfaces. Many plastics may adsorb organic contaminants from a sample and/or bleed other compounds directly from their surfaces or, particularly, from the cementing agents used to join pipe sections (5).

Sampling equipment should be constructed with materials that have the least potential for affecting the chemical or microbial constituents. The most desirable materials are glass with Teflon a close second and stainless steel probably third. The least desirable material is rubber. Unfortunately, detailed experimental data on the potential reactions between the materials and the wide range of organic compounds that serve as potential ground-water contaminants are simply not available.

Nature of possible pollution source

The area of consideration, the time available for monitoring, and potential concentration levels of pollutants all influence the sampling procedures selected. A regional or large area monitoring program may permit the use of existing wells, springs or even the baseflow of streams if these systems are compatible with the parameters of interest. If time is critical, existing sampling locations may be the only alternative. However, if the possible pollution source is relatively small, such as a landfill or lagoon, or if pollutant concentrations may be very low, such as with organics, special monitoring wells will almost surely be necessary. The number and location of additional wells needed depends on the purpose of monitoring, aquifer characteristics, and mobility of pollutants in the aquifer.

If the potential contamination source is above the water table, it may be necessary to sample the unsaturated zone to get a true picture of the threat to ground water. With the exception of chlorides, and to a lesser extent nitrates and sulfates, most pollutants can be sorbed to materials in the unsaturated zone and removed to some extent under favorable conditions (3). Therefore, it is possible to sample the ground water beneath a waste source for years and observe no contamination. This can give a false sense of security when actually pollutants are still moving very slowly through the unsaturated profile toward the ground water.

Considerable future sampling of ground water will relate to pollution or potential pollution resulting from hazardous waste disposal. Both soils and ground water in many areas may be contaminated to the extent that construction of monitoring wells and collection of samples may be hazardous to the health of workers involved. Such considerations, where applicable, should be an integral part of the process of selecting sampling procedures.

Hydrogeology

Geologic factors relate chiefly to geologic formations and their water-bearing properties, and hydrologic factors relate to the movement of water in the formations. Knowledge of the hydrogeologic framework is important from two standpoints:

(1) prediction of ground-water movement, and

(2) geochemical considerations which affect the quality of ground water.

A positive sample from a monitoring well may prove the presence of contamination in the ground water, providing the integrity of the well and sampling procedure are intact, but a negative sample does not necessarily prove the absence of contamination in the aquifer. The heterogeneous nature

of subsurface environments makes the location of sampling points a complicated and unpredictable science when trying to intercept a pollutant plume. Hydrogeologic conditions are site specific and it is impossible to prescribe standard locations for sampling points that would be applicable to all sites. In an aquifer with intergranular porosity, such as sands, gravels, sandstones and silts, water occurs in interconnected void spaces between individual particles of aquifer material. Some simplified "typical" flow patterns are illustrated in Figures 1 and 2. It is readily apparent that horizontal location of a monitoring well in relation to the pollutant source determines whether or not contaminated water is intercepted. Further, vertical location of the well screen and other well construction aspects also affect the quality of a sample collected from the well. Should the well screen be located above or below the zone of contamination, samples from this well will very likely indicate no contamination unless it is pumped sufficiently to change the ground water flow pattern. On the other hand, if the well screen is not properly sealed from other subsurface zones or if the entire saturated thickness is screened, samples from the well may represent a composite of water from several different zones, and concentrations will not be representative of any. Furthermore, such well construction may provide a conduit for the movement of contamination from one zone to another.

Gross ground water flow patterns can be developed from water level contours; however, the actual movement of a pollutant plume will be somewhat more complex. For example, in a geologic environment such as alluvium or terrace deposits involving intergranular permeabilities, the shape of the plume may be controlled by abrupt changes in permeabilities such as the channel gravels as shown in Figure 3. Such changes in permeability are common in river-deposited geologic formations and can greatly affect the shape and rate of movement of pollution plumes.

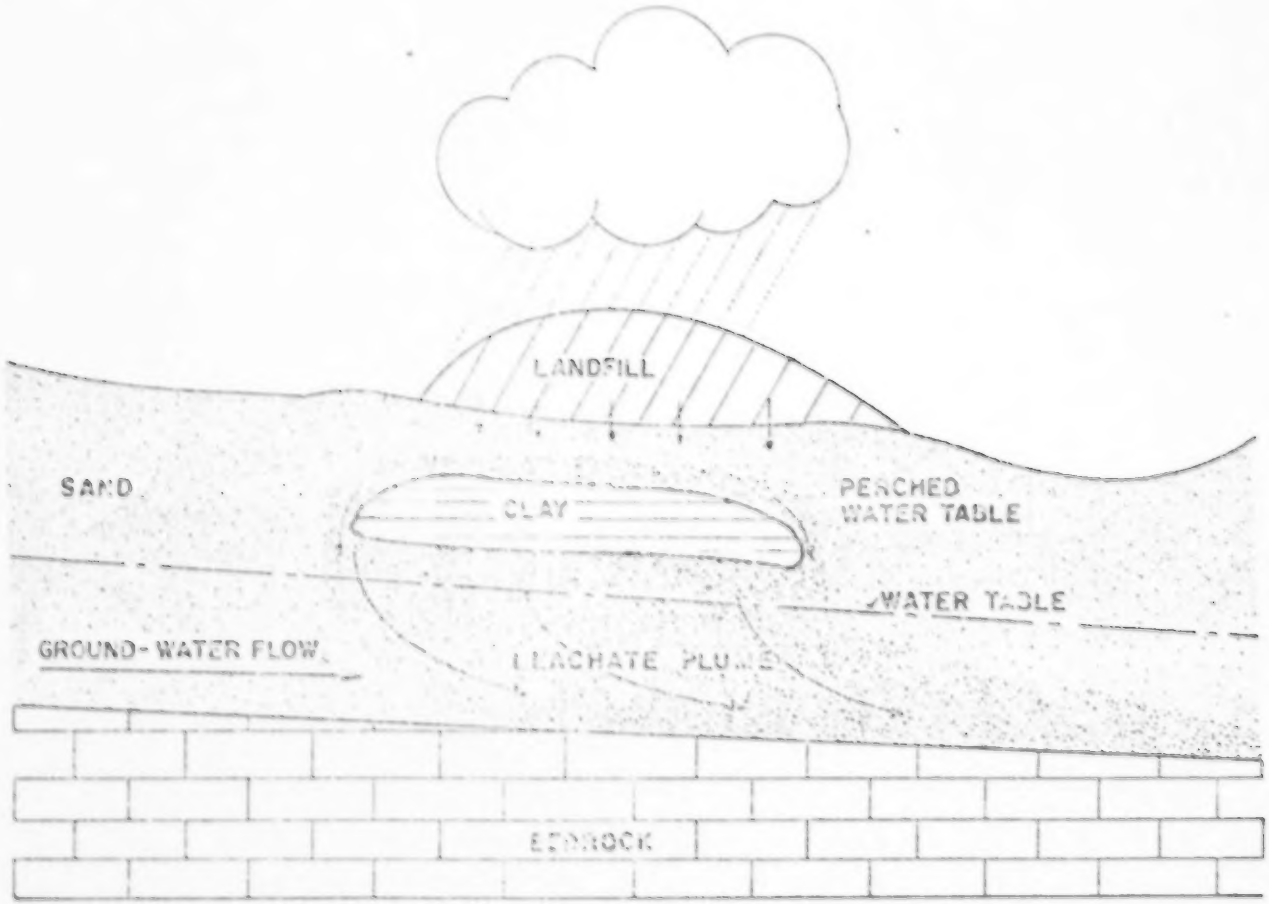

Figure 1. Permeable Sand Layer Underlain by a Clay Layer - The water table is deep. Leachate percolates downward under the landfill, forming a perched water table before finally reaching the actual water table. (3)

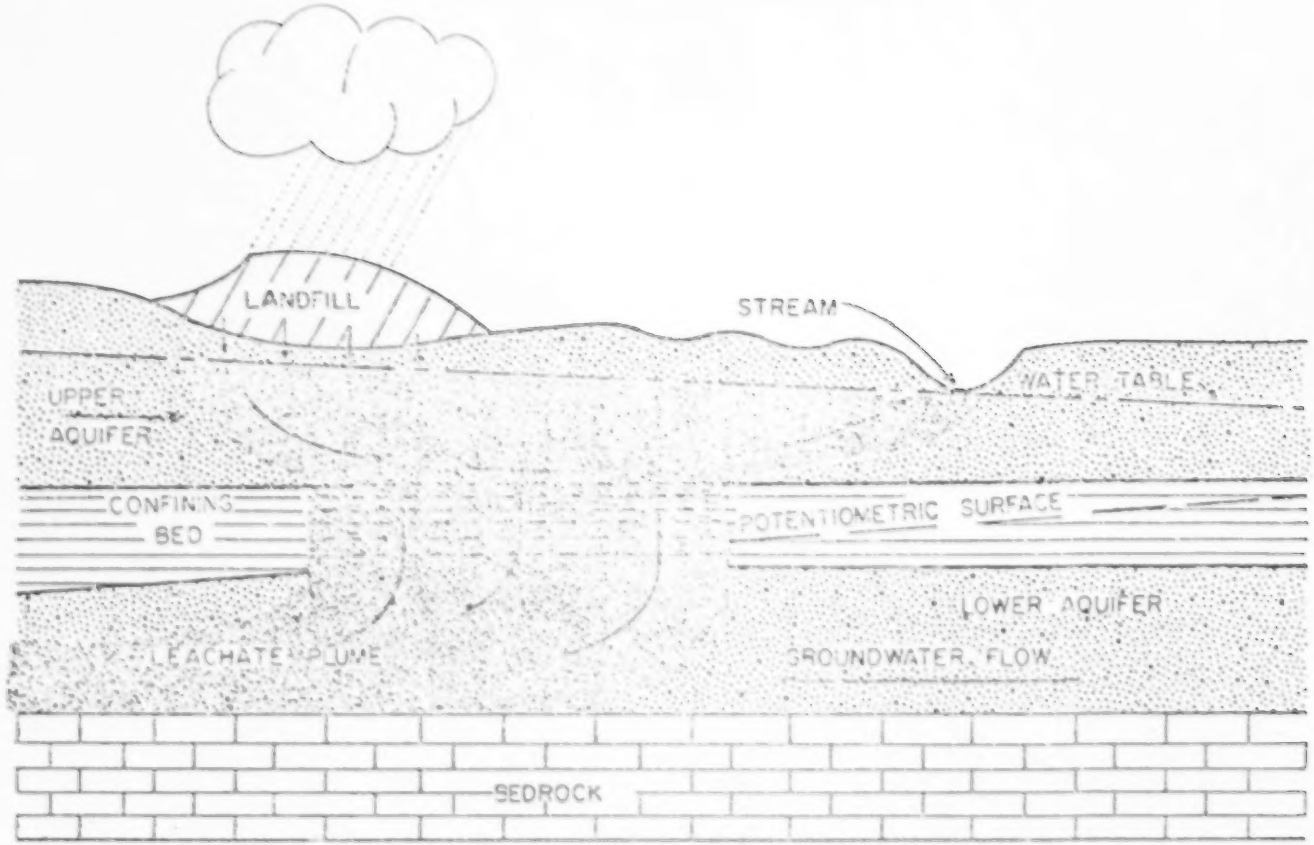

Figure 2. Two-Aquifer System with Opposite Flow Directions. Leachate first moves into and flows with the ground water in the upper aquifer. Some of the leachate eventually moves through the confining bed into the lower aquifer where it flows back beneath the landfill and away in the other direction. (3)

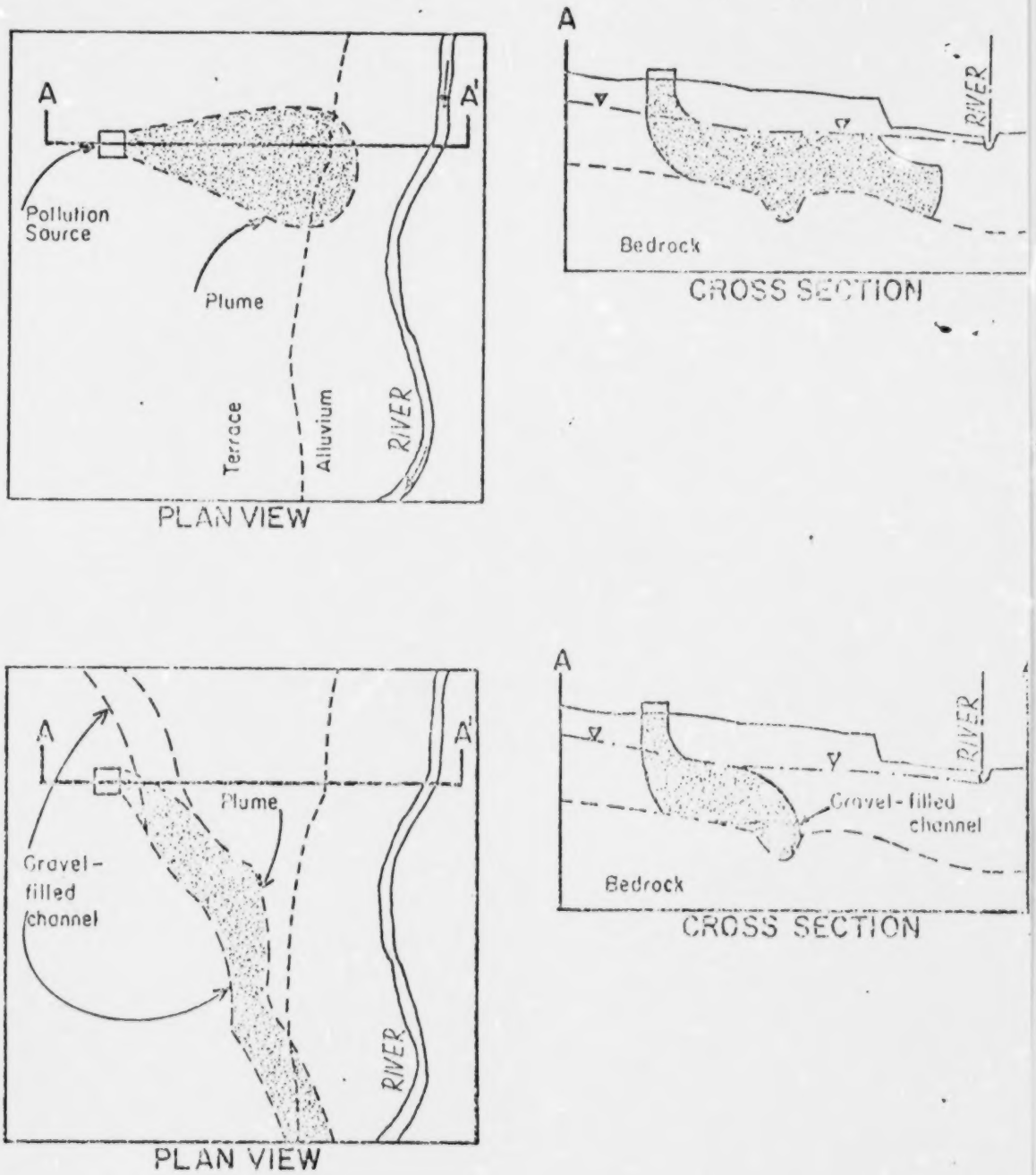

Figure 3. Effect of Permeability Change on Shape of Pollution Plume (4)

The hydrogeology is further complicated by the different flow patterns of different pollutants. Ground water contaminated with a dense pollutant such as chloride creates a plume that tends to migrate to the base of the aquifer. Conversely, lighter pollutants such as hydrocarbons tend to "float" near the top of the saturated zone. In addition, different pollutants move through the subsurface at different rates relative to the rate of water movement because of sorption, desorption, ion-exchange and biodegradation. Therefore, points of maximum concentration of the different pollutants along the ground water flow path will probably vary considerably.

Ground-water flow patterns are even less predictable in fractured rock or solution porosity aquifers than in aquifers with intergranular porosity. Flow patterns are generally controlled by fracture patterns such as those illustrated in Figures 4 and 5. Obviously, the problem in locating monitoring wells in such geology is to intercept fractures or solution channels that are hydraulically connected to the source of contamination. It is possible in many formations of this type to drill a well that is dry and move only a few meters away and drill another that has plenty of water. However, neither well may be hydraulically connected to a source of pollution only a few meters away.

In spite of the complexity, and in lieu of a detailed hydrogeologic study there are some basic guidelines that can be used in locating monitoring wells based on the considerations noted previously. One recommended monitoring method for detecting contamination at landfills is location of a background well upgradient from the landfill and a minimum of three wells downgradient and at an angle perpendicular to ground-water flow, penetrating the entire saturated thickness of the aquifer. Such an arrangement is illustrated in Figure 6 and is applicable to most potential point sources of contamination (3).

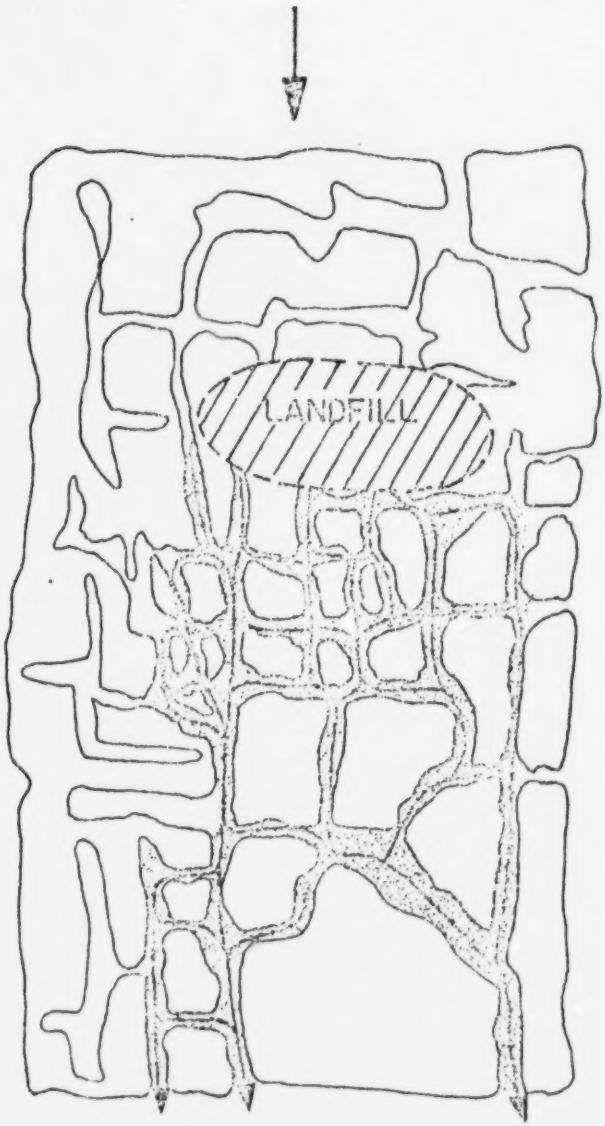

Figure 4. Solution Porosity Aquifer--Areal Flow Patterns (3)

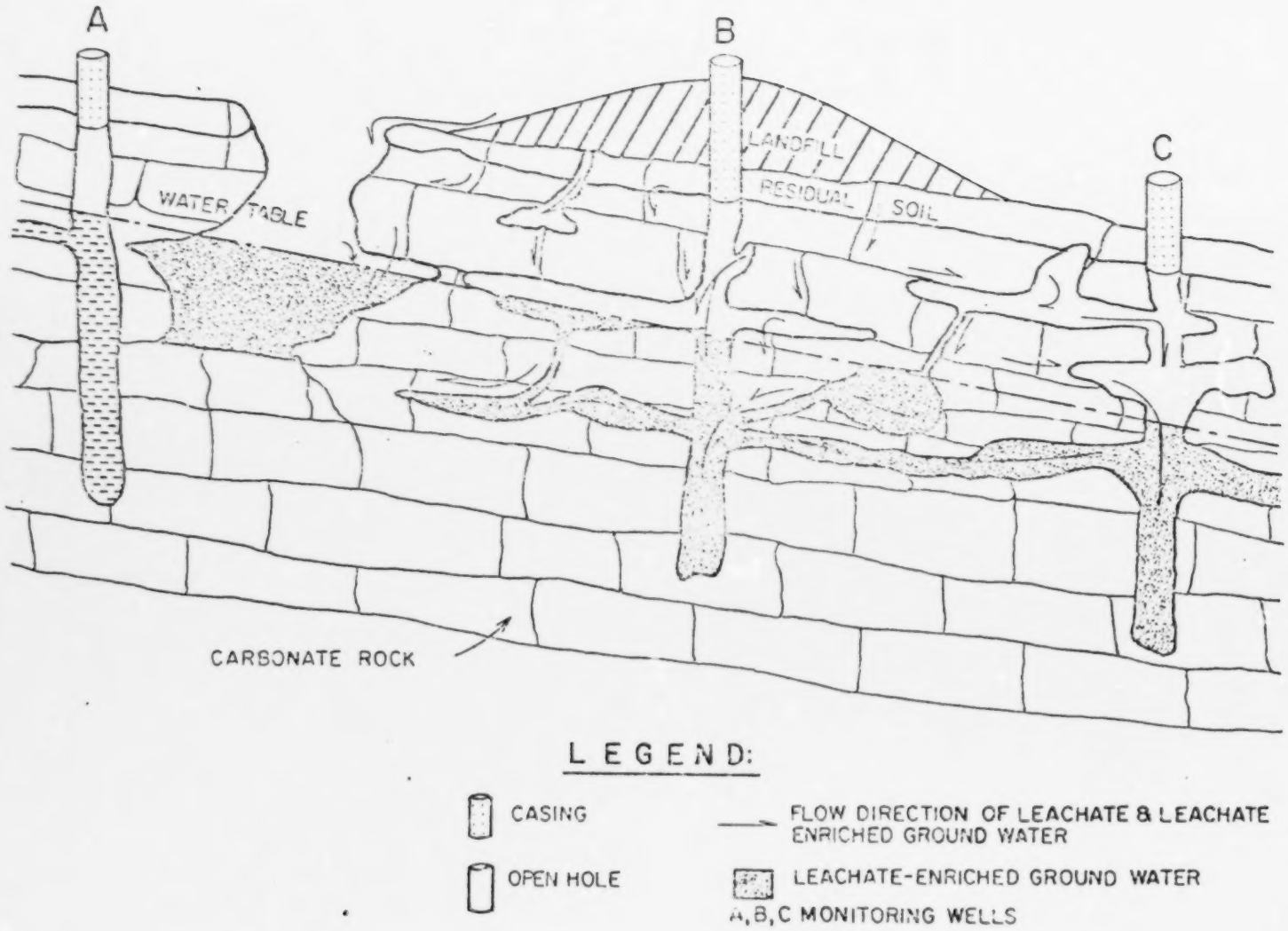

Figure 5. Solution Porosity Aquifer--Vertical Flow Patterns (3)

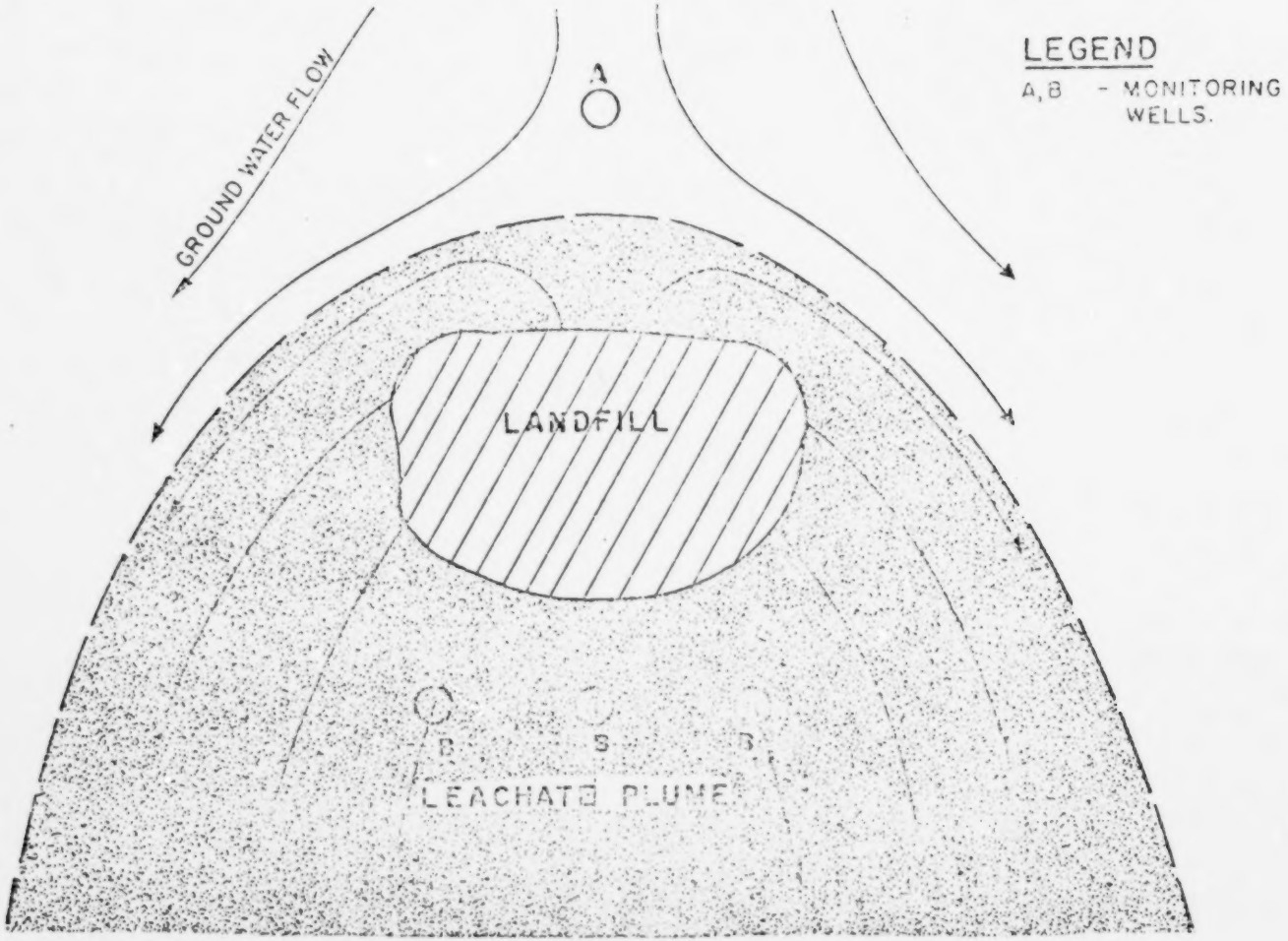

Figure 6. Idealized Monitoring Network (3)

If there is adequate reason to suggest that contamination has already occurred and the objective is to define the pollutant plume, this remains a reasonable initial approach. However, it is extremely important to locate subsequent monitoring wells one at a time, sample, and base succeeding well locations on results of previous sampling. Under no circumstances should the entire drilling budget be expended on a series of monitoring wells based entirely on the initial prediction of the direction of a pollutant plume, Even with the best of background information, there is a high probability that a large percentage of these wells will miss the pollutant plume because of the heterogeneous nature of subsurface permeabilities.

CONSTRUCTION OF MONITORING WELLS

The primary purpose of a monitoring well is to provide access to ground water. The success of a ground-water monitoring program depends on numerous factors; however, the location, design, and construction of monitoring wells is usually the most costly and non-repeatable factor. Hence, it is extremely important that the well construction be accomplished properly at the outset.

In order to accomplish the objectives of the monitoring program in the most competent and cost-effective manner, consideration must be given the proper well design and construction method that will best fit the specific objectives and the hydrogeologic conditions. The major concern during the early stages of a ground-water investigation is to assure that the drilling process does not enhance the spread of contaminants from one zone or location to another (2).

Diameter

The diameter of the casing for monitoring wells should be just sufficient to allow the sampling tool (bailer or pump) to be lowered into the well to the desired depth. The diameter of the hole into which the casing is placed must

be at least sufficiently large for the casing to fit and in many cases must be at least 5 centimeters larger to permit placement of a grout seal around the outside of the casing.

Casings and/or holes drilled much larger than the necessary minimum can, in fact, have undesired effects on the data. For example, in formations of very low permeability the excessive storage in an unnecessarily large boring can cause the water level inside the boring to be erroneously low for days or even weeks. Also, because it is usually necessary to remove water standing in the well before taking a sample of the formation water, excessive storage can complicate the water sampling procedure.

Depth

Water supply wells that may exist in an area to be monitored are often used as sampling points. Substantial care must be exercised when this is done and the results are often questionable. Some included wells may be tens of meters deep while others are hundreds of meters deep and many will be of uncertain depth and mode of completion. Water-supply wells are constructed to produce a given quantity of water, hence, they may be screened throughout a thick aquifer, through several permeable layers of an aquifer, or sometimes through two or more aquifers or discrete water-bearing layers. When this situation exists, it is probable that the hydrostatic heads are different between different layers. Under non-pumping conditions this interconnection permits water from the layer with the higher head to flow through the well and into the formation with the lower head. This condition can, of course, have substantial effect on the concentration of a pollutant obtained by pumping for a short time before sampling.

Therefore, it is often important that monitoring wells be constructed to be depth-discrete and to sample only from one specific layer without interconnection to other layers. In order to assure that this depth-discrete requirement is met, provisions for placing cement grout above and, if necessary, below the well screen on the outside of the casing must be made in the design of the wells.

Commonly (especially when sampling for contaminants lighter than water) it is desirable to sample at the water table, or top of the saturated zone in an unconfined aquifer. The screen or intake part of the well should then extend from a few feet above to a few feet below the anticipated position of the water table to allow for future water-table fluctuations. Often, under semi-confined aquifer conditions, the water will rise in the well above the top of the more permeable layer and above the top of an improperly positioned screen. Care must be exercised in these cases to extend the screen high enough to be above the water level in the formation; otherwise, light organics or other contaminants could be undetected or at least not properly quantified.

On the other hand, a contaminant can migrate along fairly restricted pathways and go undetected by depth discrete wells which are not completed at the proper depth. This danger is particularly present in a geologic environment of highly stratified formations, and in fractured rock formations.

Well Casings

As noted earlier, sampling equipment, including well casings, should be constructed of materials that have the least potential for affecting the quality parameters of the sample (6). The usual dilemma for the field investigator is the relation between cost and accuracy. In many situations, it may

be realistic to compromise some accuracy with cost. For example, if the major contaminants are already defined and they do not include substances which might bleed from PVC or cemented joints, it might be reasonable to use wells cased with the less expensive and readily obtainable PVC. Or, wells constructed of less than optimum materials might be used with a reasonable level of confidence for sampling if at least one identically-constructed well was available in a nearby, uncontaminated part of the aquifer to provide ground water samples for use as "blanks". Obviously, such a "blank" will not address the problems of adsorption on the casing material nor leaching of casing material induced by contaminants in the ground water. Careful consideration is required in each individual case; and the analytical laboratory should be fully aware of construction materials used.

Care must be given to preparation of the casing and well screens prior to installation. As a minimum, both should be washed with a detergent and rinsed thoroughly with clean water. Care should also be taken that these and other sampling materials are protected from contamination by using some type of ground cover such as plastic sheeting for temporary storage in the work area.

Drilling Methods

Although construction of a monitoring well is the most expensive aspect of a ground water quality monitoring program, the consequences of improper drilling procedures are often overlooked. Traditional water well drillers seldom appreciate the extreme care necessary to prevent the spread of contamination and drilling of water quality monitoring wells is a relatively new industry and often not properly supervised by experienced hydrogeologists.

Selection of the drilling method best suited for a particular job is based on the following factors:

1. Hydrogeologic environment
2. Water quality expected
3. Location of drilling site
4. Design of monitoring well desired
5. Availability of drilling equipment

There are several types of drilling methods used in the United States to provide access to the ground water and most of these are adequate for sampling for inorganic parameters. The principles of operation, advantages and disadvantages of the more common types of drilling techniques are discussed in more detail in other publications (4). For monitoring wells designed to sample microorganisms or organics, drilling methods that circulate drilling fluids throughout the depths of the well bore are generally not recommended.

Well Development

Well development is the process of cleaning the face of the borehole and the formation around the outside of the well screen to permit ground water to flow easily into the monitoring well. During any drilling process the side of the borehole becomes smeared with clays or other fines. This plugging action substantially reduces the permeability and retards the movement of water into the well screen. If these fines are not removed, especially in formations having low permeability, it then becomes difficult and time consuming to remove sufficient water from the well before obtaining a fresh ground-water sample because the water cannot flow easily into the well.

In the construction of high-capacity production type water wells, the development process is an important step to assure maximum hydraulic efficiency.

Even though hydraulic efficiency is not a consideration in the construction of monitoring wells, nevertheless, development should be performed for the following reasons:

1. To restore the natural permeability of the formation adjacent to the borehole to permit the water to flow into the screen easily.
2. To remove the clay, silt and other fines from the formation so that during subsequent sampling the water will not be turbid or contain suspended matter which can easily interfere with chemical analysis.

COLLECTION OF GROUND WATER SAMPLES

Even though a well being sampled may be correctly located and constructed, special precautions must be taken to ensure that the sample taken from that well is representative of the ground water at that location and that the sample is neither altered nor contaminated by the sampling and handling procedure.

To obtain a representative sample of the ground water it must be understood that the composition of the water within the well casing and in close proximity to the well is probably not representative of the overall ground water quality at that sampling site. This is due to the possible presence of drilling contaminants near the well and because important environmental conditions such as the oxidation-reduction potential may differ drastically near the well from the conditions in the surrounding water bearing materials. For these reasons it is highly desirable that a well be pumped or bailed until the well is thoroughly flushed of standing water and contains fresh water

from the aquifer. The recommended length of time required to pump or bail a well before sampling is dependent on many factors including the characteristics of the well, the hydrogeological nature of the aquifer, the type of sampling equipment being used, and the parameters of interest. The time required may range from the time needed to pump or bail one bore volume to the time needed to pump several bore volumes. A common procedure is to pump or bail the well until a minimum of four (4) to ten (10) bore-volumes have been removed.

WITHDRAWING SAMPLES

The type of system used for collection of water samples from the saturated zone of the subsurface is a function of the type and size of well construction, pumping level, type of pollutant, analytical procedures and presence or absence of permanent pumping fixtures (7). Ideally, sample withdrawal mechanisms should be completely inert; economical to manufacture; easily cleaned, sterilized and reused; able to operate at remote sites in the absence of external power sources; and capable of delivering continuous but variable flow rates for well flushing and sample collection.

Most water supply wells contain semi-permanently mounted pumps which limit the options available for ground water sampling. Existing in-place pumps may be line shaft turbines, commonly used for high capacity wells, submersible pumps very commonly used in domestic wells for high-head, low capacity applications, and more recently for municipal and industrial uses. and jet pumps commonly used for shallow, low capacity domestic water supplies. The advantage of in-place pumps are that water samples are readily available and non-representative stagnant water in the well bore is generally not a problem. The disadvantages are that excessive pumping can dilute or increase the contaminant

concentrations from what is representative of the sampling point, that water supply wells may produce water from more than one aquifer, and contamination and/or adsorption may be a problem when sampling for organics.

The advantage to collecting water samples from monitoring wells without in-place pumps is in the flexibility of selecting equipment and procedures. The principal disadvantage is the possibility of a non-representative sample either through collecting stagnant water that is in the well bore or introducing contamination from the surface by the sampling equipment or procedures.

Special Sampling Considerations for Organic Samples

Sampling for organic parameters is a new and in no way, a routine procedure at this time. The equipment and methods in current use are largely in the research state. The concepts are fundamental, however, and any particular item can be modified to suit actual field needs. Furthermore, these rather expensive and sophisticated procedures may not be necessary for sampling or monitoring all areas. New techniques and materials are continuously being examined, which in turn should lead to the development of more sophisticated yet more economical sampling methods.

Grab samples of ground water for non-volatile organic analysis may be collected by utilizing the system shown in Figure 7 where the sampled water contacts only sterile glass and Teflon, and the water table is within suction lift. The sampled water is then carefully transferred to appropriate glass sample containers for shipment to the laboratory.

For sampling at depths beyond suction lift, a noncontaminating submersible pump should be used to pump the ground water to the surface, through scrupulously cleaned Teflon tubing, directly into appropriate sample containers.

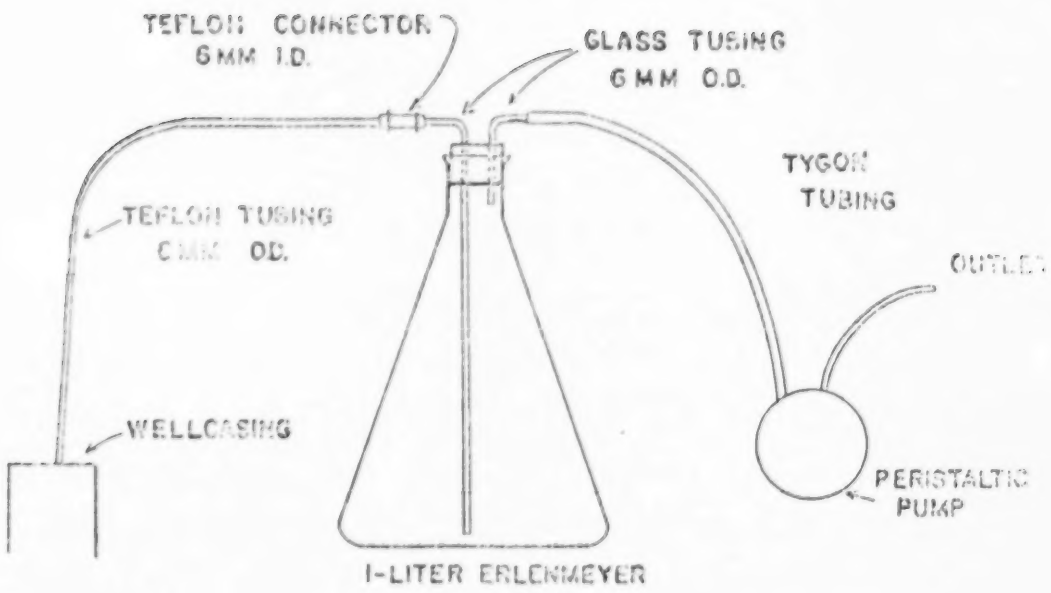

Figure 7. System for Grab Sampling (5)

The most commonly employed sample containers are 40 ml glass vials for analyses requiring small sample volumes, such as total organic carbon, and one-gallon jugs for analyses requiring relatively large volumes, such as extractable organics. Both types of containers are equipped with Teflon-lined screw caps. Like all glassware used in the sampling and analytical procedures, sample containers are thoroughly cleaned prior to use by washing with detergent, rinsing extensively with tap water followed by high purity deionized water and heating to 560° for two hours.

Grab samples of ground water to be analyzed for highly volatile organics by the Bellar-Lichtenberg volatile organic analysis (VOA) method (9) are usually obtained by means of a Teflon bailer noted in Figure 8. Use of vacuum systems or air-lift systems is less desirable than bailers for VOA samples because of possible stripping of highly volatile constituents from the sample under the reduced or elevated pressure occurring in systems using pumps.

Continuous procedures, using selected adsorbents to concentrate and recover organic constituents from relatively large volumes of ground water, may be employed for sampling organic pollutants in situations where the analytical sensitivity and sample uniformity attainable by grab sampling are inadequate. These procedures are applicable for most organic pollutants except those of very high volatility (5).

Volatile Organics in the Unsaturated Zone (5)

For investigations pertaining to organic pollution of ground water, it is often desirable to sample water in the unsaturated zone to detect and follow the movement of pollutants that are migrating toward the water table. This is a particularly difficult task in the case of highly volatile compounds,

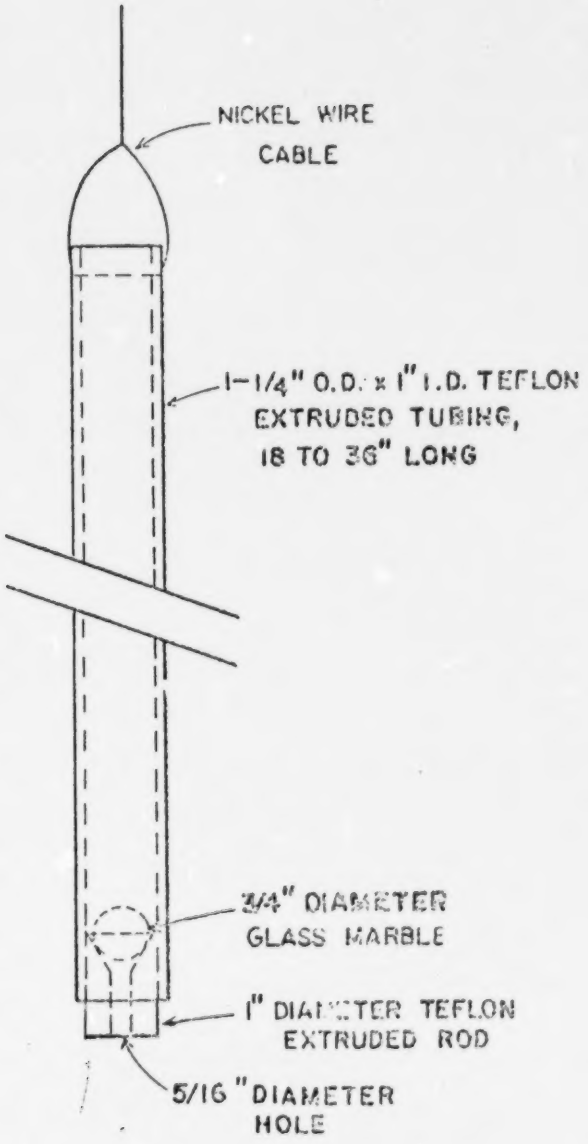

Figure 8. Teflon Bailer (6)

including the low molecular weight chlorinated hydrocarbons such as trichloroethylene. A number of these compounds are widely used and released into the environment in significant quantities, exhibit some form of toxicity, particularly carcinogenicity, and are being increasingly implicated in cases of ground water pollution.

Soil-water samples may be collected using the device depicted in Figure 9, which consists of a sampler, a purging apparatus, and a trap connected to sources of nitrogen gas and vacuum. The device is basically a suction lysimeter and, consequently, suffers from the limitations of such equipment. However, there is evidence that similar systems may potentially be used to measure soil gases emanating from volatile organic pollutants in the ground water (8). Such application could greatly reduce the drilling required to monitor pollutant plumes in ground water quality investigations.

SAMPLING SUBSURFACE EARTH MATERIALS

A common misconception regarding ground-water monitoring is that absence of contaminants in the ground water precludes a contamination problem. In many cases, an effective evaluation of the potential impact on ground water quality of activities releasing pollutants into the earth's crust, requires samples of subsurface earth materials, both saturated and unsaturated, as well as ground water samples. There are several principal reasons for this requirement:

(1) Only by analysis of earth materials from the unsaturated zone underlying pollutant-releasing activities can those pollutants which are moving very slowly toward the water table because of sorption and/or physical impediment be detected and their rates

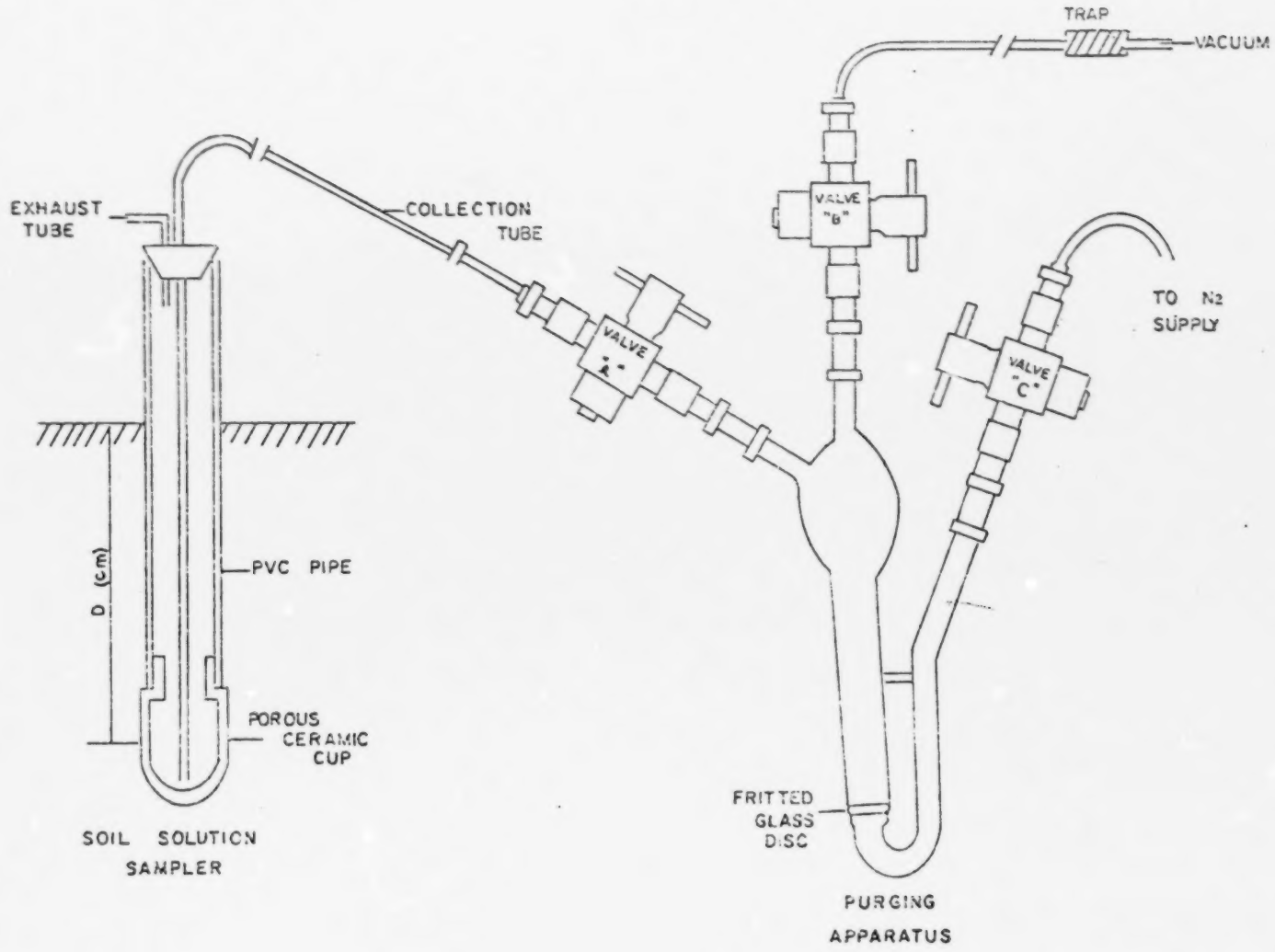

Figure 9. Soil-Water Sampling Device for Volatile Organics (5)

of movement and degradation measured. Almost all pollutants are attenuated to some degree in the subsurface, especially in the unsaturated zone. The degree of attenuation and rate of movement varies greatly between different pollutants and different subsurface conditions but many of the mobile pollutants may not be detected in ground water until the activities releasing them have been in operation for protracted periods. Because of their potential for long-term pollution of ground water, it is imperative that the behavior of these pollutants in the subsurface be established at the earliest practicable time.

(2) Analysis of pollutants in subsurface material samples from the zone of saturation are needed for a realistic evaluation of the total extent and probable longivity of pollution in an aquifer. Such analyses provide a measure of the quantity of pollutants which are sorbed on aquifer materials and which are in equilibrium with, and in essence serve as a reservoir for, pollutants in solution in the adjacent ground water.

(3) Microbial populations which may be involved in the biological alteration of pollutants in subsurface formations are likely to be in such close association with subsurface materials that they will not be present in well waters in numbers which are quantitatively indicative of their presence in the formations; hence, analysis of subsurface materials are needed for accurate evaluation of such populations.

(4) Even when the best well construction and ground-water sampling

procedures are used, it is difficult to completely eliminate the possibility that contaminating surface microbes may be present in ground-water samples. Materials taken from the interior of cores carefully obtained from the zone of saturation probably provide the most authentic samples of aquifer microorganisms that can be obtained.

As with ground water samples, successful sampling of subsurface earth materials requires both acquisition of cores of subsurface materials at desired depths in a manner minimizing potential contamination and proper handling and processing of the core material obtained to insure its integrity and produce samples suitable for determinative analytical procedures.

There are a variety of procedures and equipment that have been used to collect earth materials for classification and identification of physical characteristics. Tools as simple as a shovel or backhoe can and have been used and a number of designed samplers have also been used for this purpose. Because of the ability to penetrate greater depths and to maintain the physical integrity of the samples, most designed samplers employ some type of coring mechanism. The most common procedures use a thin-wall steel tube (core barrel) which is forced into the undisturbed soil at the bottom of a bore hole. Core barrels are generally from one inch to three inches in diameter and 12 to 24 inches long. When the core barrel is retrieved, friction will usually retain the sample inside, at least in most unsaturated materials.

The bore hole can be made with a continuous flight or hollow stem auger, rotary core drill or other drilling method. For water quality analyses, it is generally recommended that the drilling method employed avoid the use of drilling fluids since these greatly increase the potential for sample con-

tamination. Similarly, it is also recommended that core sampling equipment avoid the use of drilling fluids.

Sampling in the saturated zone encompasses a number of additional problems of sample integrity. Maintaining an open bore hole while collecting a core sample is extremely difficult, especially in fine sand aquifers. Use of a hollow-stem auger can alleviate this problem in many situations but in extreme situations, removal of the auger plug may permit sand to flow up the interior of the auger before the core sample can be taken

Sampling in a saturated zone also increases problems of contamination. The coring tube must travel through water in the bore hole and this water will almost surely contaminate at least the outside of the core sample. It is necessary, especially for microbial analyses, that the outside of the cores be discarded and that only the interior be used for sample analyses. For deeper sampling, beyond the practical capability of augers, methods for collecting uncontaminated samples have not been proven.

The procedures to follow in processing a sample will depend on the type of analyses and the situation in the field. Regardless of the types of analyses to be performed, processing should be as soon as possible. When dealing with cores, the core may be processed in the field or if necessary the core may be retained in the core barrel, placed in a sterile plastic bag, sealed, and transported to the laboratory. This procedure works sufficiently well for cores of relatively compact, dry materials, but is not satisfactory for loose or very wet materials which will shift within the core barrel. Recommendations on storage of samples before processing vary widely from maintaining samples at the temperatures at which they are sampled to refrigerating them.

Split tubes or sectioned tubes are sometimes used to collect cores so as to permit access to the core material with minimal disturbance. Dunlap, et al. recommends a single piece coring tube and the use of a hydraulic extruding device when sampling subsurface solids for organics or microorganisms. As soon as the core is obtained, the sample tube is placed into an extruding device. As the core sample is forced out of the tube, the first 5 to 8 cm are cut off with a sterile scalpel and discarded, or used for analyses of chemical or physical parameters. The center of the cores is then subsampled to obtain material suitable for microbial analysis by pushing a sterile 1.3 cm I.D. stainless steel tube into the core for about 15 cm. The subsample is extruded with a sterile rod into appropriate containers.

The type of sample container which is used is dependent on the type of analysis to be performed. For culturing of aerobic organisms any sterile container is suitable if analyses are to be performed within a few hours. If there is to be a significant delay before the sample is used, care is exercised to keep the sample in a manner that prevents major changes in the microbial content. Polyethylene bags, which allow the passage of air but not water vapor, are good sample containers because the samples have access to air and yet are kept from drying.

Since subsurface environments of any depth are usually reducing in nature, the enumeration and identification of anaerobic microorganisms is essential if the total microbial composition of the systems is to be known. Because many anaerobic bacteria are known to be extremely sensitive to oxygen, it is important that samples which will be used in anaerobic culturing procedures be handled in a manner that minimizes exposure to air. This can be accomplished

by extruding subsamples into sterile glass tubes from which the air is replaced quickly with an oxygen-free gas.

Samples to be analyzed for parameters such as biomass or viruses require specialized processing procedures which are continually changing as the state of art develops. Because such procedures are rapidly being improved, recommendations of any specific procedure are beyond the scope of this paper.

After a sub-core for microbial analysis has been removed from the parent core, a 10 cm (4 in) length of core material for chemical analysis is obtained. For organic analyses, the sample is extruded directly into a thoroughly cleaned disposable aluminum baking pan, covered tightly with clean aluminum foil, and placed in an insulated polystyrene box containing liquid nitrogen to quick-freeze the sample material. Typical locations for microbial and organic samples in a parent core are shown in Figure 10.

The frozen samples are returned to the laboratory on dry ice, stored temporarily at -45°C in a low-temperature freezer, and freeze-dried as soon as possible in a bulk type freeze dryer. Each sample of dried solids is carefully crushed and mixed to obtain a better degree of homogeneity. These samples are then transferred to thoroughly cleaned 475 ml (16 oz) wide-mouth jars with Teflon lined caps and stored at -45°C until subjected to further processing or analysis.

Samples of dried core material may be subjected to gross organic analysis, such as total organic carbon, without further processing. Samples suitable for more definitive analysis, including identification of individual compounds, are prepared by solvent extraction of the solid samples.

SUMMARY

Regulatory agencies must base their environmental policies on available technology to minimize potential pollution. They must also monitor the effects of various activities on the surrounding environment. The use of subsurface samples collected from cores and wells has been, and probably will continue to be, the method for interpreting the effects of man's activities on ground water quality.

The perception that one acquires of the processes that control the movement of contaminants in the subsurface is often dependent on the monitoring approach used. The selection of monitoring procedures must balance the reliability of the various aspects of the sampling and analytical procedures involved. It is of little value if the analytical procedure is accurate to within plus or minus ten percent if results vary an order of magnitude due to deficiencies in the sampling program.

On the other hand, the concept of a true aquifer concentration or a "representative" sample must be kept in perspective. Typically, ground water contains different concentrations both vertically and areally throughout an aquifer. Such heterogeneity must be considered when constructing an image based on water quality data collected.

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